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# Economic costs of invasive alien species across Europe

Phillip J. Haubrock[1,2*], Anna J. Turbelin[3*], Ross N. Cuthbert[4,5*], Ana Novoa[6*], Nigel G. Taylor[7*], Elena Angulo[3], Liliana Ballesteros-Mejia[3], Thomas W. Bodey[8,9], César Capinha[10], Christophe Diagne[3], Franz Essl[11], Marina Golivets[12], Natalia Kirichenko[13,14], Melina Kourantidou[15,16], Boris Leroy[17], David Renault[18,19], Laura Verbrugge[20,21], Franck Courchamp[3,*]

**1** *Senckenberg Research Institute and Natural History Museum Frankfurt, Department of River Ecology and Conservation, 63571 Gelnhausen, Germany* **2** *University of South Bohemia in České Budějovice, Faculty of Fisheries and Protection of Waters, South Bohemian Research Center of Aquaculture and Biodiversity of Hydrocenoses, Zátiší 728/II, 389 25, Vodňany, Czech Republic* **3** *Université Paris-Saclay, CNRS, AgroParisTech, Ecologie Systématique Evolution, 91405, Orsay, France* **4** *Queen's University Belfast, School of Biological Sciences, 19 Chlorine Gardens, Belfast, BT9 5DL, Northern Ireland, UK* **5** *GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel, 24105, Kiel, Germany* **6** *Czech Academy of Sciences, Institute of Botany, Department of Invasion Ecology, CZ-25243, Průhonice, Czech Republic* **7** *Tour du Valat, Research Institute for the Conservation of Mediterranean Wetlands, 13200, Arles, France* **8** *University of Aberdeen, King's College, School of Biological Sciences, Aberdeen, AB24 3FX, UK* **9** *University of Exeter, Penryn, Environment & Sustainability Institute, Cornwall, TR10 9FE, UK* **10** *Universidade de Lisboa, Centre for Geographical Studies, Institute of Geography and Spatial Planning, Edifício IGOT, Rua Branca Edmée Marques, 1600-276, Lisbon, Portugal* **11** *University Vienna, Department for Botany and Biodiversity Research, BioInvasions, Global Change, Macroecology-Group, Rennweg 14, 1030, Vienna, Austria* **12** *Helmholtz-Centre for Environmental Research – UFZ, Department of Community Ecology, 06120, Halle (Saale), Germany* **13** *Sukachev Institute of Forest Siberian Branch of Russian Academy of Sciences, Federal Research Center «Krasnoyarsk Science Center SB RAS», Krasnoyarsk, 660036, Russia* **14** *Siberian Federal University, Krasnoyarsk, 660041, Russia* **15** *Woods Hole Oceanographic Institution, Marine Policy Center, Woods Hole, MA 02543, United States* **16** *University of Southern Denmark, Department of Sociology, Environmental and Business Economics, Esbjerg, 6700, Denmark* **17** *Unité Biologie des Organismes et Ecosystèmes Aquatiques (BOREA UMR 7208), Muséum National d'Histoire Naturelle, Sorbonne Universités, Université de Caen Normandie, Université des Antilles, CNRS, IRD, Paris, France* **18** *University of Rennes 1, UMR CNRS 6553, EcoBio, Rennes, France* **19** *Institut Universitaire de France, 1 rue Descartes, Paris, France* **20** *Aalto University, Water & Development Research Group, Espoo, Finland* **21** *University of Helsinki, Faculty of Agriculture and Forestry, Department of Forest Sciences, P.O. Box 27, 00014, Helsinki, Finland*

Corresponding authors: Phillip J. Haubrock (Phillip.Haubrock@Senckenberg.de);
Franck Courchamp (Franck.Courchamp@u-psud.fr)

* These authors contributed equally.

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## Abstract
Biological invasions continue to threaten the stability of ecosystems and societies that are dependent on their services. Whilst the ecological impacts of invasive alien species (IAS) have been widely reported in recent decades, there remains a paucity of information concerning their economic impacts. Europe has strong trade and transport links with the rest of the world, facilitating hundreds of IAS incursions, and largely centralised decision-making frameworks. The present study is the first comprehensive and detailed effort that quantifies the costs of IAS collectively across European countries and examines temporal trends in these data. In addition, the distributions of costs across countries, socioeconomic sectors and taxonomic groups are examined, as are socio-economic correlates of management and damage costs. Total costs of IAS in Europe summed to US$140.20 billion (or €116.61 billion) between 1960 and 2020, with the majority (60%) being damage-related and impacting multiple sectors. Costs were also geographically widespread but dominated by impacts in large western and central European countries, i.e. the UK, Spain, France, and Germany. Human population size, land area, GDP, and tourism were significant predictors of invasion costs, with management costs additionally predicted by numbers of introduced species, research effort and trade. Temporally, invasion costs have increased exponentially through time, with up to US$23.58 billion (€19.64 billion) in 2013, and US$139.56 billion (€116.24 billion) in impacts extrapolated in 2020. Importantly, although these costs are substantial, there remain knowledge gaps on several geographic and taxonomic scales, indicating that these costs are severely underestimated. We, thus, urge increased and improved cost reporting for economic impacts of IAS and coordinated international action to prevent further spread and mitigate impacts of IAS populations.

## Abstract in Czech
**Ekonomické náklady na invazní nepůvodní druhy v celé Evropě.** Biologické invaze nadále ohrožují stabilitu ekosystémů i naší společnosti, která je na těchto ekosystémech závislá. Zatímco ekologické dopady nepůvodních invazních druhů byly v posledních desetiletích podrobně studovány, existuje jen mámo informací o ekonomických dopadech těchto invazí. Evropa má silné obchodní a dopravní vazby se zbytkem světa i značně decentralizované řízení, což usnadňuje stovkám nepůvodních druhů jejich invazní vpád. Tato studie je prvním komplexním a podrobným příspěvkem, který kvantifikuje ekonomické náklady spojené s invazními druhy, jež se vyskytují v evropských zemí, a to včetně jejich časového vývoje. Dále bylo zkoumáno rozdělení nákladů mezi zeměmi, socioekonomickými odvětvími, taxonomickými skupinami a typy nákladů. Celkové náklady invazních druhů v Evropě dosáhly v letech 1960 až 2020 výše 140,20 miliardy americké dolary (116.6 miliardy eur), přičemž většina (60%) byla spojena s přímými škodami a měla dopad na více odvětví. Tyto náklady byly plošné, ale dominovaly dopady ve velkých západoevropských a středoevropských zemích, jako je Velká Británie, Španělsko, Francie a Německo. Velikost lidské populace, rozloha státu, výše hrubého domácího produktu a úroveň cestovního ruchu byly významnými prediktory nákladů způsobených invazními druhy, přičemž náklady na jejich management byly dány počtem těchto druhů, výzkumným úsilím na ně vynaloženým a úrovní rozvoje obchodu. Časově nákladovost invazních druhů rostla z 23,58 miliardy americké dolary (19.6 miliardy eur) v roce 2013 na odhadovaných 139,56 miliardy americké dolary (116.2 miliardy eur) v roce 2020. Ačkoliv jsou tyto náklady značné, existují stále

významné mezery v našich znalostech o jejich úrovni v řadě evropských regionů, stejně jako pro početné taxonomické skupiny invazních druhů. Zde prezentovaná výše škod je tak stále významnou měrou podhodnocena. Vyzýváme tedy ke zvýšenému a lepšímu vykazování ekonomických nákladů způsobených invazními druhy a koordinovaným mezinárodní aktivitám, jež mají za cíl omezovat šíření a dopady těchto druhů.

## Abstract in French

**Coûts économiques des espèces exotiques envahissantes en Europe.** Les invasions biologiques continuent de menacer la stabilité des écosystèmes et des sociétés qui dépendent de leurs services. Alors que les impacts écologiques des espèces exotiques envahissantes (EEE) ont été largement signalés au cours des dernières décennies, il reste peu d'informations concernant les impacts économiques des EEE. L'Europe a de solides liens commerciaux et de transport avec le reste du monde, facilitant des centaines d'incursions d'EEE et des cadres décisionnels largement centralisés. Cette étude est le premier effort complet et détaillé qui quantifie les coûts des EEE collectivement dans les pays européens et examine les tendances temporelles de ces données. En outre, la répartition des coûts entre les pays, les secteurs socio-économiques et les groupes taxonomiques est examinée, de même que les corrélats socio-économiques des coûts de gestion et des dommages. Le coût total des EEE en Europe s'est élevé à 140,20 milliards de dollars américains (ou 116,61 milliards d'euros) entre 1960 et 2020, la majorité (60%) étant liée aux dommages et ayant un impact sur plusieurs secteurs. Les coûts étaient également géographiquement répandus, mais dominés par les impacts dans les grands pays d'Europe occidentale et centrale, à savoir le Royaume-Uni, l'Espagne, la France et l'Allemagne. La taille de la population humaine, la superficie terrestre, le PIB et le tourisme étaient des prédicteurs importants des coûts d'invasion, les coûts de gestion étant en outre prédits par le nombre d'espèces introduites, l'effort de recherche et le commerce. Temporairement, les coûts d'invasion ont augmenté de façon exponentielle au fil du temps, atteignant jusqu'à 23,58 milliards de dollars (19,64 milliards d'euros) en 2013 et 139,56 milliards de dollars (116,24 milliards d'euros) d'impacts extrapolés en 2020. Il est important de noter qu'il subsiste des lacunes dans les connaissances à plusieurs échelles géographiques et taxonomiques bien que ces coûts soient substantiels, ce qui indique que ces coûts sont fortement sous-estimés. Nous suggérons donc une augmentation et une amélioration des rapports sur les coûts des impacts économiques des EEE et une action internationale coordonnée pour prévenir la propagation et atténuer les impacts des populations d'EEE.

## Abstract in Russian

**Экономические издержки инвазивных чужеродных видов в Европе.** Биологические инвазии продолжают угрожать стабильности экосистем и зависящих от экосистемных услуг обществ. Несмотря на активное документирование экологических воздействий инвазионных чужеродных видов (invasive alien species, IAS) в последние десятилетия, данные об экономических потерях, ассоциированных с инвазиями, все еще малочисленны. Европа имеет прочные торговые и транспортные связи с остальным миром, которые могут способствовать инвазиям сотен чужеродных видов, и характеризуется выраженной централизованностью структур, отвечающих за принятие управленческих решений. Данная работа является первым подробным комплексным исследованием, позволившим оценить выраженный в денежном эквиваленте ущерб от инвазий чужеродных видов в европейских странах, и проанализировать временные тренды экономических потерь. Нами также изучалось распределение убытков по странам, социально-экономическим секторам и таксономическим группам, а кроме того, оценивались социально-экономические корреляты затрат на мониторинг и контроль инвазий. В Европе в 1960–2020 гг. общие затраты, ассоциированные с инвазионными чужеродными видами, составили 140.20 млрд долларов США (или 116.61 млрд евро), и большая часть (60%) затрат была связана с убытками в разных экономических секторах. Сведения по экономическим потерям получены из многих регионов Европы, но их преобладающий объем поступает из крупных стран Западной и Центральной Европы, в частности, Великобритании, Испании, Франции и Германии. Численность населения, площадь суши, размер валового внутреннего продукта (ВВП) и туризм являются важными предикторами экономических потерь, включая затраты на контроль инвайдеров, спрогнозированные на основе числа интродуцированных видов, исследовательских усилий и торговой активности. В Европе ущерб от инвазий показывает экспоненциальный рост: от 23.58 млрд долларов США (1964 млрд евро) в 2013 г. до 139.56 млрд долларов США (116.24 млрд евро) по прогнозным оценкам в 2020 г. Важно отметить, что эти затраты хотя и являются значительными, все еще сохраняются пробелы в знаниях об экономических потерях по отдельным таксонам инвайдеров и отдельным европейским странам, что указывает на недооценку тотального ущерба от инвазий в Европе. Таким образом, мы призываем к улучшению отчетности по экономическим последствиям инвазий чужеродных видов и к координированным международным действиям по предотвращению дальнейшего распространения видов-инвайдеров и смягчению их воздействия.

## Abstract in Spanish

**Costos económicos de las especies exóticas invasoras en Europa.** Las invasiones biológicas continúan amenazando la estabilidad de los ecosistemas y de las sociedades que dependen de sus servicios. Si bien en las últimas décadas los impactos ecológicos de las especies exóticas invasoras (EEI) han sido ampliamente registrados, sigue habiendo escasez de información sobre sus impactos económicos. Europa tiene fuertes vínculos comerciales y de transporte con el resto del mundo, lo que facilita la introducción de cientos de EEI y la existencia de marcos de toma de decisiones en gran parte centralizados. Este estudio representa el primer esfuerzo completo y detallado de cuantificar los costos económicos de las EEI en los países europeos y examina las tendencias temporales en estos datos. Además, analiza las distribuciones de costos entre países, sectores socioeconómicos y grupos taxonómicos, así como las correlaciones socioeconómicas de los costos de gestión y daños de las EEI. Los costos totales de las EEI en Europa ascendieron a 140.20 mil millones de dólares (o 116.61 mil millones de euros) entre 1960 y 2020, y la mayoría (60%) están relacionados con daños y afectan a múltiples sectores. Los costos están geográficamente extendidos pero dominados por los daños de las EEI en los grandes países de Europa occidental y central, es decir, Reino Unido, España, Francia y Alemania. La población humana, la superficie terrestre, el PIB y el turismo fueron predictores importantes de los costos relacionados con los daños de las EEI, mientras que para los costos de gestión, el número de especies introducidas, el esfuerzo de investigación y el comercio fueron los predictores más importantes. Temporalmente, los costos de invasión han aumentado exponencialmente a lo largo del tiempo, con hasta 23.58 mil millones de dólares (19.64 mil millones de euros) en 2013 y 139.56 mil millones de dólares (116.24 mil millones de euros) en impactos extrapolados en 2020. Sigue habiendo lagunas de conocimiento en varias escalas geográficas y taxonómicas, lo que indica que estos costos están muy subestimados. Por lo tanto, instamos a que se incrementen y mejoren los informes de costos de los impactos económicos de las EEI y a la acción internacional coordinada para evitar una mayor propagación de EEI y mitigar sus impactos.

## Abstract in Greek

**Οικονομικό κόστος επεμβατικών ξένων ειδών σε ολόκληρη την Ευρώπη.** Οι βιολογικές εισβολές εξακολουθούν να απειλούν την σταθερότητα των οικοσυστημάτων και των κοινωνιών που εξαρτώνται από τις υπηρεσίες τους. Ενώ οι οικολογικές επιπτώσεις των εισβολικών ειδών έχουν καταγραφεί ευρέως τις τελευταίες δεκαετίες, εξακολουθεί να υπάρχει μια έλλειψη πληροφορίας για τις οικονομικές επιπτώσεις των ειδών αυτών. Η Ευρώπη συνδέεται στενά με τον υπόλοιπο κόσμο μέσω του δικτύου εμπορίου και μεταφοράς, επιτρέποντας έτσι εκατοντάδες περιστατικά βιολογικών εισβολών και σε μεγάλο βαθμό κεντροποιημένα συστήματα λήψης αποφάσεων. Η παρούσα εργασία είναι η πρώτη ολοκληρωμένη και λεπτομερής προσπάθεια που ποσοτικοποιεί τα κόστη των εισβολικών ειδών συνολικά για τις Ευρωπαϊκές χώρες και εξετάζει τις τάσεις των δεδομένων αυτών στην πορεία του χρόνου. Επιπρόσθετα, αναλύεται η κατανομή του κόστους σε χώρες, τομείς της οικονομίας και της κοινωνίας, καθώς και ταξινομικές ομάδες, όπως επίσης αναλύονται και κοινωνικό-οικονομικές συσχετίσεις του κόστους από βλάβες και διαχείριση. Τα συνολικά κόστη των εισβολικών ειδών στην Ευρώπη εκτιμήθηκαν σε US 140.20 δις (ή € 116.61 δις) για το διάστημα 1960 – 2020, με την πλειονότητα αυτών (60%) να αποδίδονται σε βλάβες και να επηρεάζουν πολλαπλούς τομείς. Επίσης η γεωγραφική κατανομή του κόστους ήταν ευρεία, ωστόσο κυριάρχησαν οι επιπτώσεις σε μεγάλες χώρες της κεντρικής και δυτικής Ευρώπης, π.χ. Ηνωμένο Βασίλειο, Ισπανία, Γαλλία και Γερμανία. Το μέγεθος του πληθυσμού, η έκταση, το ΑΕΠ και ο τουρισμός βρέθηκαν να είναι σημαντικοί παράμετροι που εξηγούν τα κόστη των εισβολικών ειδών, με τον αριθμό των εισαχθέντων ειδών, την ερευνητική προσπάθεια και το εμπόριο να εξηγούν επιπρόσθετα τα κόστη διαχείρισης. Τα κόστη των εισβολικών ειδών έδειξαν να αυξάνονται εκθετικά στη διάρκεια του χρόνου, με κόστη που φτάνουν τα US$ 23.58 δις (€ 19.64 δις) το 2013 και US$ 139.56 δις (€ 116.24 δις) σε επιπτώσεις τα κόστη των οποίων προεκτάθηκαν ως το 2020. Είναι σημαντικό το ότι παρόλο που τα κόστη αυτά είναι υψηλά, εξακολουθούν να υπάρχουν κενά γνώσης σε διάφορες γεωγραφικές και ταξινομικές κλίμακες, υποδεικνύοντας ότι τα κόστη έχουν υποεκτιμηθεί σε μεγάλο βαθμό. Έτσι προτρέπουμε αύξηση και βελτίωση στην καταγραφή των οικονομικών επιπτώσεων και συντονισμένη δράση σε διεθνές επίπεδο για την αποφυγή επιπλέον επέκτασης και για την μείωση των επιπτώσεων των εισβολικών πληθυσμών.

## Abstract in Italian

**Costi economici delle specie esotiche invasive in tutta Europa.** Le invasioni biologiche continuano a minacciare la stabilità degli ecosistemi e delle società dipendenti dai loro servizi. Mentre gli impatti ecologici delle specie aliene invasive (SAI) sono stati largamente riportati negli ultimi decenni, rimane una scarsità di informazioni riguardo agli impatti economici delle SAI. L'Europa ha forti rapporti di commercio e trasporto col resto del mondo, favorendo centinaia di incursioni di SAI. Questo studio è il primo sforzo comprensivo e dettagliato a quantificare collettivamente i costi delle SAI nei Paesi europei e ad esaminare le tendenze temporali di questi dati. Inoltre, sono esaminate le distribuzioni dei costi tra Paesi, settori socioeconomici e gruppi tassonomici, così come i correlati socioeconomici dei costi della gestione e dei danni. I costi totali delle SAI in Europa tra il 1960 e il 2020 ammontano a 140.20 miliardi di $ americani (116.61 miliardi di €), la maggior parte dei quali (60%) sono legati ai danni e colpiscono più settori. I costi sono anche geograficamente diffusi, ma dominati dagli impatti nei grandi Paesi dell'Europa occidentale e centrale, ovvero Regno Unito, Spagna, Francia e Germania. La dimensione della popolazione umana, l'estensione dell'area, PIL e il turismo sono predittori significativi dei costi delle invasioni, con i costi gestionali predetti anche dal numero di specie introdotte, gli sforzi di ricerca e il commercio. Nel tempo, i costi delle invasioni sono aumentati esponenzialmente, con un picco estrapolato di impatti di 23.58 miliardi di $ americani (19.64 miliardi di €) nel 2013 e di 139.56 miliardi di $ americani (116.24 miliardi di €) nel 2020. Importantemente, sebbene questi costi siano notevoli, rimangono ancora delle lacune nella conoscenza di alcune scale geografiche e tassonomiche, il che indica che questi costi sono considerevolmente sottostimati. Pertanto, abbiamo bisogno di una maggiore e migliore rendicontazione dei costi per gli impatti economici delle SAI e di un'azione internazionale coordinata per prevenire ulteriori diffusioni e mitigare gli impatti delle SAI.

## Abstract in German

**Wirtschaftliche Kosten invasiver gebietsfremder Arten in ganz Europa.** Biologische Invasionen bedrohen die Stabilität von Ökosystemen und Gesellschaften, die von ihren Dienstleistungen abhängig sind. Während über die ökologischen Auswirkungen invasiver gebietsfremder Arten in den letzten Jahrzehnten ausführlich berichtet wurde, fehlen Informationen über die wirtschaftlichen Auswirkungen. Europa verfügt über starke Handels- und Verkehrsverbindungen mit dem Rest der Welt, wodurch die Etablierung hunderter von nicht-heimischen Arten erleichtert wird. Die vorliegende Studie ist die erste umfassende und detaillierte Studie, die die Kosten von gebietsfremden Arten in allen europäischen Ländern gemeinsam quantifiziert und zeitliche Trends untersucht. Darüber hinaus werden die Kostenverteilung auf Länder, sozioökonomische Sektoren und taxonomische Gruppen sowie sozioökonomische Korrelationen von Management- und Schadenskosten untersucht. Die Gesamtkosten der IAS in Europa beliefen sich zwischen 1960 und 2020 auf 140.20

Mrd. USD (oder 116.61 Mrd. EUR), wobei die Mehrheit (60%) schadensbedingt war und mehrere Sektoren betraf. Die Kosten waren auch geografisch weit verbreitet, wurden jedoch von Auswirkungen in großen westeuropäischen und mitteleuropäischen Ländern dominiert, d.h. in Großbritannien, Spanien, Frankreich und Deutschland. Die Bevölkerungszahl, die Landfläche, das BIP und der Tourismus waren wichtige Indikatoren für die Kosten biologischer Invasionen, wobei die Verwaltungskosten zusätzlich durch die Anzahl der eingeführten Arten, den Forschungsaufwand und den Handel prognostiziert wurden. Zeitlich gesehen sind diese Kosten im Laufe der Zeit, mit bis zu 23.58 Mrd. USD (19.64 Mrd. EUR) im Jahr 2013 und 139.56 Mrd. USD (116.24 Mrd. EUR) im Jahr 2020, exponentiell angestiegen. Obwohl die Kosten erheblich sind, verbleiben wichtige geografische und taxonomische Wissenslücken, wodurch diese Kosten stark unterschätzt werden. Wir fordern daher eine verstärkte und verbesserte Kosten-Berichterstattung für die wirtschaftlichen Auswirkungen gebietsfremder Arten in Europa sowie koordinierte internationale Maßnahmen, um eine weitere Verbreitung zu verhindern und dessen Auswirkungen zu mildern.

## Abstract in Irish

**Costais eacnamaíocha speiceas coimhthíoch ionrach ar fud na hEorpa.** Tá ionraí bitheolaíochta go fóill ina mbagairt ar chobhsaíocht éiceachóras agus sochaithe atá ag brath ar a gcuid seirbhísí. Cé gur tuairiscíodh tionchair éiceolaíochta speicis choimhthíocha ionracha (SCI) go forleathan le blianta beaga anuas, tá ganntanas eolais ann go fóill maidir leis na tionchair gheilleagracha a bhaineann le SCI. Tá caidreamh láidir trádála agus iompair ag an Eoraip leis an chuid eile den domhan, rud a éascaíonn na céadta ionradh SCI, agus creata cinnteoireachta aici atá láraithe den chuid is mó. Is é an staidéar seo an chéad iarracht chuimsitheach, mhionsonraithe a mheasann ar bhonn cainníochtúil comhchostais SCI ar fud thíortha na hEorpa trí chéile agus a scrúdaíonn treochtaí ama sna sonraí seo. Lena chois sin, scrúdaítear ann dáileadh costas ó thír go tír, ó earnáil shocheacnamaíoch go chéile, agus ó ghrúpa tacsanomaíoch go chéile, mar aon le comhghaolaigh shocheacnamaíocha costais bhainistithe agus damáiste. SA$140.20 billiún (nó €116.61 billiún) na costais a bhí ar SCI san iomlán san Eoraip idir 1960 agus 2020, agus bhí baint ag a bhformhór (60%) le damáiste agus tionchar acu sin ar earnálacha iomadúla. Bhí costais leitheadach chomh maith, ó thaobh na tíreolaíochta de, ach is i dtíortha móra in iarthar agus i lár na hEorpa, i. an Ríocht Aontaithe, an Spáinn, an Fhrainc, agus an Ghearmáin, a bhí na tionchair ba shuntasaí. Ba réamhaithriseoirí tábhachtacha ar chostais ionraidh iad líon na ndaoine, limistéar talún, OTI, agus an turasóireacht, agus ba iad líon na speiceas a tugadh isteach, dua taighde, agus trádáil ba bhonn le costais bhainistithe a thuar chomh maith leis sin. Ó thaobh ama de, tá costais ionraidh i ndiaidh méadú as cuimse trí na blianta agus eachtarshuíodh suas le SA$23.58 billiún (€19.64 billiún) in 2013 agus suas le SA$139.56 billiún (€116.24 billiún) in 2020 de bharr tionchar. Is tábhachtach a aithint, cé go bhfuil na costais seo suntasach, go bhfuil bearnaí eolais ann go fóill ar roinnt scálaí tíreolaíocha agus tacsanomaíocha, rud a thaispeánann gur gannmheasadh na costais seo go mór. Molaimid, dá réir sin, méadú agus feabhsú ar thuairisciú costas maidir le tionchair gheilleagracha SCI agus gníomh Idirnáisiúnta comheagraithe chun nach leathfaidh líon SCI a thuilleadh agus chun a dtionchair a mhaolú.

## Abstract in Croatian

**Ekonomski troškovi invazivnih stranih vrsta širom Europe.** Biološke invazije nastavljaju prijetiti stabilnosti ekosustava i društvima koja ovise o njihovim uslugama. Iako su posljednjim desetljećima ekološki utjecaji invazivnih stranih vrsta široko izvještavani, i dalje nema dovoljno podataka o ekonomskim utjecajima invazivnih stranih vrsta. Europa ima snažne trgovinske i prometne veze s ostatkom svijeta, olakšavajući stotine upada invazivnih stranih vrsta, i uglavnom centralizirane okvire za donošenje odluka. Ova studija je prvi sveobuhvatan i detaljan napor koji kvantificira troškove invazivnih stranih vrsta kolektivno diljem europskih zemalja i ispituje privremene trendove u tim podacima. Uz to se ispituje raspodjela troškova po zemljama, socioekonomskim sektorima i taksonomskim skupinama, kao i socioekonomske korelacije troškova upravljanja i štete. Ukupni troškovi ivnazivnih stranih vrsta u Europi iznosili su 140.20 milijardi američkih dolara (ili 116.61 milijardi eura) između 1960. i 2020. godine, pri čemu je većina (60%) povezana sa štetom i utječe na više sektora. Troškovi su također bili zemljopisno rašireni, ali su dominirali utjecaji u velikim zemljama zapadne i srednje Europe, tj. Velikoj Britaniji, Španjolskoj, Francuskoj i Njemačkoj. Veličina ljudske populacije, površina zemljišta, BDP i turizam bili su značajni prognozeri troškova invazije, a troškovi upravljanja dodatno su predviđeni brojem unesenih vrsta, istraživačkim naporima i trgovinom. Troškovi invazije su se s vremenom eksponencijalno povećali na 23.58 milijardi američkih dolara (19.64 milijardi eura) do 2013. godine i na 139..56 milijardi američkih dolara (116.24 milijardi eura) za utjecaje koji su ekstrapolirani u 2020 godini. Iako su ti troškovi znatni važno je naglasiti da i dalje postoje praznine u znanju na nekoliko zemljopisnih i taksonomskih razmjera, što ukazuje da su ti troškovi ozbiljno podcijenjeni. Stoga zahtijevamo povećano i poboljšano izvještavanje o troškovima za ekonomske utjecaje invazivnih stranih vrsta i koordiniranu međunarodnu akciju kako bi se spriječilo daljnje širenje i ublažili utjecaji populacija invazivnih stranih vrsta.

**Abstract in Arabic**

**التكاليف الاقتصادية للأنواع الغريبة الغازية في أوروبا.** من المعلوم أن أوروبا، بالإضافة إلى مسألة تمركز القرار الاقتصادي، تتمتع بروابط تجارية مهمة وحركة نقل واسعة النطاق مع بقية العالم، الأمر الذي يسهل معه دخول العديد من "الأنواع الغريبة". وبالرغم من الجهود المهمة المبذولة، في العقود الأخيرة، في مجال "الاستعلام" وتوفير إمكانات "الإبلاغ" عن التأثيرات البيئية "للأنواع الغريبة الغازية"، إلا أنه يسجل ندرة بخصوص المعلومات المتعلقة بالتأثير على المجال الاقتصادي؛ وهو ما جعل الخبراء في هذا المجال يرفعون شعار "الغزو البيولوجي يُهدد استقرار النظم البيئية والمجتمعات التي تعتمد على خدماتها".

الدراسة التي بين أيدينا، تعتبر، اليوم، الأولى من نوعها من حيث الجهد الجماعي والتفصيل الدقيق فيما يخص تكاليف "الأنواع الغريبة الغازية" في البلدان الأوروبية، وتدرس الاتجاهات الزمنية الممكنة في البيانات المحصل عليها. وتنطلق الدراسة من تحليل توزيع التكاليف عبر البلدان والقطاعات الاجتماعية والاقتصادية والمجموعات التصنيفية، وكذلك تكلفة الأضرار المرتبطة بتدبير الروابط الاجتماعية-الاقتصادية.

وحسب هذه الدراسة، بلغ إجمالي تكاليف "الأنواع الغريبة الغازية" في أوروبا 140.20 مليار دولار أمريكي (أو 116.61 مليار يورو) بين عامي 1960 و2020 وغالبيتها (60٪) مرتبطة بالأضرار، كما تؤثر هذه الأنواع على قطاعات متعددة. ويسجل بهذا الخصوص، أن التكاليف ظهرت منتشرة جغرافياً في كل أوروبا مع هيمنة التأثيرات في دول أوروبا الوسطى والغربية، مثل المملكة المتحدة وإسبانيا وفرنسا وألمانيا. كما شكل عدد السكان، ومساحة البلد، والناتج المحلي الإجمالي والسياحة المؤشرات الأساسية لتحديد تكاليف الغزو البيولوجي، مع تكاليف التدبير الإضافية المتوقعة من خلال عدد الأنواع التي تم إدخالها وجهود البحث والتجارة.

زمنيا، إذن، زادت تكاليف "الغزو البيولوجي" بشكل كبير لتصل إلى 23.58 مليار دولار أمريكي (19.64 مليار يورو) في عام 2013، و139.56 مليار دولار أمريكي (116.24 مليار يورو) في التأثيرات التي تم استقراءها في سنة 2020. والأهم من ذلك، هو أنه على الرغم من أن هذه التكاليف كبيرة، فإنه لا تزال هناك فجوات معرفية على عدة نطاقات جغرافية وتصنيفية، مما يشير إلى أن هذه التكاليف تم التقليل من شأنها بشدة.

وعطفا على ما سبق، فإننا نحث، كتوصية، العمل على زيادة وتحسين تقارير التكلفة للتأثيرات الاقتصادية "للأنواع الغازات الغريبة" والعمل الدولي المنظم من أجل منع المزيد من الانتشار والتخفيف من آثار مجموعات الأنواع الغريبة الغازية.

**Keywords**

Bodiversity, European Union, InvaCost, monetary impacts, non-native biota, socio-economic correlates, socioeconomic sectors

## Introduction

Despite an increasing number of indicators and alarming reports on the rapid decline of biodiversity globally (Díaz et al. 2020; Haubrock et al. 2021b), efforts to halt biodiversity losses have remained insufficient (Hulme 2009; Scalera 2010; Rayment et al. 2018). Notwithstanding the multiple signals of the rapid decline of natural capital worldwide, global economic resources allocated to prevent and mitigate such losses have not proven adequate to meet conservation management goals, or have been designated inefficiently (Murdoch et al. 2007; Underwood et al. 2008; Stokstad 2010; McCarthy et al. 2012; Waldron et al. 2013, 2017). In a highly connected world, with escalating trade and demand for resources, the number of invasive alien species (IAS) is rapidly increasing (Seebens et al. 2017). In fact, biological invasions are one of the most eminent global threats to biodiversity, ecosystem services and livelihoods (Bellard et al. 2016; Pysek et al. 2020). Whilst much effort has been directed to improve understanding of the ecological impacts of IAS, knowledge about their economic impacts is limited to a few species, habitats, and/or regions, and often only to direct costs that are straightforward to properly quantify or estimate (Kettunen et al. 2009; Bradshaw et al. 2016).

As a historic epicenter of migration, tourism and trade, Europe represents a hub for alien species introductions (Turbelin et al. 2017). Although several studies have attempted to assess the environmental and socio-economic impacts of IAS in Europe (Weber and Gut 2004; Vilà et al. 2009, 2010; Keller et al. 2011), only a few have quantified them in monetary terms (Gren et al. 2009; Kettunen et al. 2009). Pimentel et al. (2000, 2005) and Kettunen et al. (2009) were among the first to attempt to summarize the economic impact of IAS on a continental scale, raising awareness of the actual and potential costs associated with IAS (Hensley 2012). However, due to limited availability of published data at the time, they had to rely heavily on personal communications and technical reports. Kettunen et al. (2009) reported total annual costs of IAS of ~€12 billion across Europe, although given the scarcity of data available at this time, sources and methods used were generally scant (Bradshaw et al. 2016; Diagne et al. 2020a, 2020b). Other publications have attempted to collectively assess the costs of IAS (Hoffmann and Broadhurst 2016), for different organism types (Lovell et al. 2006; Van der Veer and Nentwig 2015; Bradshaw et al. 2016; Barbet-Massin et al. 2020; Cuthbert et al. 2021b), and for different countries (e.g. Great Britain: Williams et al. 2010). Scalera (2010), for example, reviewed EU-funded projects on IAS and reported an investment of more than €132 million between 1992 and 2006. Substantial variation in estimations of management and damage costs of IAS and the methodologies used, due to many sources being somewhat scattered and providing only anecdotal information at local, regional and national scales, have limited the estimation of IAS costs so far (e.g. Britton et al. 2010; Oreska and Aldridge 2011). Importantly, in several cases, data reporting the costs of IAS are often found in the grey literature (IUCN 2018), not easily accessible, sometimes not publicly available and not written in English (Angulo et al. 2021b).

This lack of reliable, readily-available data on IAS costs remains a critical knowledge gap in assessing the diversity of impacts associated with biological invasions. Its absence can give the false impression that this information is limited, as costs may be rarely reported in a systematic manner. In addition, the lack of reliable and comprehensive quantification of IAS costs leads to an absence of an economic rationale serving as a solid basis for decision-making by policy makers and other stakeholders. A robust and transparent assessment of costs of IAS at the scale of continents, European states, or trading blocs is currently lacking. While cost estimates are useful at a national scale, their calculation at broader scales may be even more crucial. For example, within both the European Union (EU) and European Economic Area (EEA), where trade agreements encourage the free movement of goods and potentially facilitate the spread of IAS, information on the economic impact of each species could demonstrate the requirements for a greater or lower emphasis on continent-wide biosecurity and control measures. Such an evidence base would also indicate the extent to which different countries are investing into relevant actions, and where funds or political pressure may be targeted to enhance the economic security of both nations and wider trading blocs.

In this context, the InvaCost initiative (Diagne et al. 2020a, 2020b) tackles this lack of collated data, presenting a comprehensive and urgently-needed database that can be used to thoroughly investigate the costs of IAS at a range of scales, from subnational to continental. Here, we use the InvaCost database to (i) describe Europe-wide impacts of IAS among countries, cost types and economic sectors, (ii) investigate the causes for differences in these costs among European countries, and (iii) examine the temporal trends in costs of IAS in recent decades.

# Methods

## Data compilation and extraction

IAS in InvaCost represent those which have established and spread in novel ranges and have reported socioeconomic impacts (i.e. monetary costs). To estimate the cost of biological invasions on the European economy, we used the InvaCost database (InvaCost v.1.0; Diagne et al. 2020a and subsequent additions, see below). The InvaCost v.1.0 database comprises 2,419 entries of reported economic costs of IAS retrieved from published peer-reviewed and grey literature (as of December 2017). Data in InvaCost v.1.0 were retrieved from publications in English identified in the Web of Science platform (https://webofknowledge.com/), Google Scholar (https://scholar.google.com/), Google (https://www.google.com/), and through direct contacts with regional experts. InvaCost is a living database for which correction of potential errors and addition of new cost entries are further expected (Diagne et al. 2020a). The InvaCost v.1.0 database has been extended recently with 5,212 data entries from non-English sources (Angulo et al. 2020). This dataset was derived from a search in fifteen languages, including languages relevant for Europe: French, Spanish, Portuguese, German, Greek, Dutch, Ukrainian, and Russian (as of May 2020). The cost search protocol was similar to the original InvaCost protocol (Diagne et al. 2020a); however, the majority of these entries resulted from targeted searches, i.e. via searching web pages and directly contacting IAS experts and stakeholders to request for potentially unpublished/publicly unavailable documents containing cost information. We further added supplementary cost data from new references containing cost information, obtained through the same search protocol as used for InvaCost v.1.0 (2,374 entries; Ballesteros-Mejia et al. 2020). Individual cost records were standardized to a common currency: 2017 US$ (see Diagne et al. 2020a for detailed information on conversion; exchange rate for 2017: US$1 = €0.8852; World Bank 2020).

## Data processing

First, we cleaned the raw data in the InvaCost database. We removed obvious duplicate or overlapping costs, identified through chains of citations or identical cost details. Where necessary, we split aggregated costs (e.g. if the InvaCost database contained a single cost for Europe but the original source contained costs for each individual country). The period of estimation across reported costs varied considerably, spanning periods of several months to several years. For the purpose of the analysis, and in order to obtain comparable IAS costs, we considered all costs for a period of less than a year as annual costs, and re-calculated costs covering several years on an annual basis. This was performed using the "expandYearlyCosts" function of the 'invacost' package version 0.3–4 (Leroy et al. 2020) in R version 4.0.2 (R Core Team 2020). We thus estimated average annual costs represented in the InvaCost database. Deriving the total cumulative cost of invasions over time requires consideration of the probable duration time of each cost occurrence. The duration consisted of the number of years between the probable starting ("Probable_starting_year") and ending ("Probable_ending_year") years of the costs reported by each publication included in the InvaCost database (Diagne et al. 2020a). When information was missing for the starting year, we conservatively considered the publication year of the original reference. For the ending year of costs, however, information was missing only for costs likely to be repeated over years (i.e. "potentially ongoing", contrary to "one-time" costs occurring only once along a specific period). Therefore, we considered that these costs might still occur until 2020: the last year from which publications were included in InvaCost and in the non-English dataset. Subsequently, to obtain a comparable total cumulative cost for each estimate over each defined invasion period, we multiplied each annual estimate by the respective duration (in years). All analyses were performed for the period from 1960 to 2020, as monetary exchange rates could not be obtained from official institutions (e.g. World Bank) prior to 1960. The overall number of cost entries before expansion was 4867 and 7461 after expansion, whereby "expansion" refers to the process of annualising cost data of different durations using the aforementioned "expandYearlyCosts" function.

## Economic cost descriptors

To examine the costs of IAS incurred within Europe, we filtered the full dataset based on the geographic region "Europe". We provide our final dataset used as a supplement (Suppl. material 1). Naturally, these analyses include species which are native in some European countries, but invasive in others (e.g. European rabbit), but invasion costs are only documented in novel ranges. Costs that were incurred from multiple or unspecified taxa were included in analyses but categorised as "Diverse/Unspecified". The resulting invasion cost totals were examined according to different descriptive fields of the most up-to-date database available when writing this manuscript:

i. Official_country: describing the national origin of the listed cost for European countries only. For technical reasons, Kosovo and Serbia were considered as one country, while Turkey was excluded entirely as costs were not clearly attributable to Europe. For transcontinental Russia, we considered and presented only the European part for the total cost, while not considering it for further analyses which were based on fully European countries. As such, Turkey and Russia were excluded from detailed analyses to avoid ambiguities given their transcontinental nature, whereby there was a lack of European-scale indicators that would permit comparison with other European states. Moreover, the underlying spatial resolution of data often precluded determination of European and Asian contributions as costs were presented at national, not regional, scales. Overseas territories (e.g. French Guiana, Reunion, Pitcairn and the Canary Islands) were also excluded;

ii. Method_reliability: illustrating the perceived reliability of cost estimates based on the type of publication and method of estimation. Estimates in peer-reviewed publications or official reports, or with documented, repeatable and/or traceable methods were designated as "High" reliability (hereafter, "reliable"); all other estimates were designated as "Low" reliability (Diagne et al. 2020a);

iii. Implementation: referring to whether the cost estimate was actually realised in the invaded habitat ("Observed") or whether it was expected ("Potential");

iv. Type_of_cost_merged: grouping of costs according to the categories: (a) "Damage-Loss" referring to damages or losses incurred by invasion (e.g. costs for damage repair, resource losses, medical care), (b) "Management" comprising control-related expenditure (for example monitoring, prevention, management, eradication, research, communication) and money spent on education and maintenance costs, (c) "Diverse/Unspecified" including mixed damage-loss and management costs (cases where reported costs were not clearly distinguished among cost types);

v. Impacted_sector: the activity, societal or market sector that was impacted by the cost (Suppl. material 2); note that individual cost entries not allocated to a single sector were classified under "Mixed" in the "Impacted_sector" column.

## Economic cost correlations

We first explored whether the two main types of costs, "Management" and "Damage-Loss", can be explained by country-specific factors. To do so, we calculated the cumulative reliable observed costs for 1960–2020 of each type of cost at the country level and selected a range of socio-economic variables that we hypothesize could be linked to biological invasions (Suppl. material 3). Then, we calculated Spearman rank correlations ($r_s$) between the country-level expenditures and damage costs and the selected socio-economic variables using the R package 'ggpubr' (Kassambara 2017). Further, we also explored correlations between country-level expenditures and damage costs.

## Spatial and taxonomic connectivity of costs

To examine the spatial and taxonomic connectivity of invasion costs in Europe, we constructed a bipartite network composed of two types of nodes: (1) countries and (2) taxonomic groupings (excluding studies reporting costs on diverse taxonomic groups). For taxonomic groupings, we also captured habitat types of each taxon (e.g. "terrestrial arthropod" instead of "arthropod"). When an IAS group economically impacted a given country, a link was drawn between the associated nodes with a weight proportional to the economic impact. As such, the size of the nodes, and thickness of the links, correspond to the magnitude of cumulative economic costs incurred for the 1960–2020 period. To investigate spatial and taxonomic patterns of costs in Europe, we applied the Map Equation community-detection algorithm (version 0.19.12, www.mapequation.org; Rosvall and Bergstrom 2008). This approach groups nodes into clusters with high intragroup connectivity, enabling clusters of similar costs to be established (i.e. countries sharing costs from the same invasive taxa) (Leroy et al. 2019). Network analyses were performed with the 'biogeonetworks' R package version 0.1.2 (Leroy 2020), and the network was represented with Gephi 0.9.2 using the ForceAtlas2 algorithm (Bastian et al. 2009).

## Temporal dynamics of accumulated costs

For the temporal estimation of the average annual costs, we used the 'invacost' package in R (Leroy et al. 2020). This package allows modelling the trend of costs over time with an array of linear and non-linear model types and enables a summary and comparison of their respective outputs. Given the evidence that numbers of IAS show no sign of saturation (Seebens et al. 2017), we expected their associated costs to be stable or increasing. In addition, we can expect a time lag between the occurrence of costs, their publication, and their reporting in InvaCost (Leroy et al. 2020). Therefore, as per Seebens et al. (2017), we excluded recent years from model calibration. The last eight years appear to have less than 75% completeness within the global InvaCost database (Leroy et al. 2020); therefore, we chose to exclude them from model calibration (i.e. years post-2013).

A range of modelling techniques were then applied to model the temporal dynamics of reported costs ("modelCosts" function): ordinary least squares regressions (linear, quadratic), robust regressions (linear, quadratic – R package 'robustbase'; Maechler et al. 2020), multivariate additive regression splines (MARS – R package 'earth'; Milborrow et al. 2018), generalised additive models (GAM – R package 'mgcv'; Wood et al. 2016) and quantile regressions (quantiles 0.1, 0.5, 0.9 – R package 'quantreg'; Koenker 2020). These approaches enabled quantification of average annual costs, measurements of variation in cost estimates over time and assessment of predictive performance across models (based on RMSE). Model selection was also performed on the basis of techniques that are relatively robust to issues of heteroskedasticity, outliers and temporal autocorrelation that are common in econometric data (Leroy et al. 2020). Moreover, the diverse modelling approach enabled potential generalities in trends to be determined, such as whether all models were consistent in projecting cost increases through time.

As a separate analysis, we further used the aforementioned combination of approaches to examine temporal trends in economic costs, based on the GDP-qualified economic costs of the European countries from the year the cost occurred (i.e., costs divided by GDP per year), elucidating whether invasion costs are still increasing relative to economic growth. For this, we utilized robust regressions modelling as implemented in the 'invacost' package, since those are based on iteratively reweighted least squares, which makes them less sensitive to outliers compared to ordinary least square regressions (Yohai 1987; Koller and Stahel 2011).

# Results

## Composition and scale of economic costs

Overall, economic losses associated with biological invasions were obtained for 39 European countries (including the European part of Russia). Costs of biological invasions in Europe between 1960 and 2020 accumulated to a reported total of US$140.20 billion (or €116.61 billion). The vast majority of the reported costs exhibited a high degree of reliability (US$113.16 billion; n = 7034; 80.71%). Slightly more than half of cost estimates (US$77.66 billion; n = 6489; 55.4%) were derived from actual observations, while the rest (US$62.54 billion; n = 972; 44.6%) were potential costs that were not empirically observed (Figure 1). Economic costs were spread unevenly across countries (Figure 1): the United Kingdom (UK) (US$17.60 billion, n = 709), Spain (US$16.19 billion, n = 4162), France (US$11.41 billion, n = 1268), Germany (US$9.76 billion, n = 193), European Russia (US$8.48 billion; n = 29), Portugal (US$7.89 billion, n = 60), and the Netherlands (US$3.44 billion; n = 161) reported the largest invasion costs (Figure 1). Considering only reliable observed costs (US$50.97 billion; n = 6153), the UK again reported the highest total (US$6.89 billion; n = 538), and was followed by European Russia (US$1.82 billion; n = 10), Ukraine (US$1.51 billion; n = 96), and Romania (US$1.61 billion; n = 3). Reliable observed costs reported for other countries were less than US$1 billion per country.

The majority of total reported economic costs were related to damage and loss (total costs: US$84.18 billion; 60%; reliable observed costs: US$21.52 billion; 42%) (Figure 2a). Management costs (e.g. for prevention, control, education) totalled to US$28.17 billion (20%) considering all costs, and US$2.76 billion (5%) when considering only reliable observed costs. The remaining costs were classified under the category "Mixed" (i.e. combining both damage-loss and management; total costs: US$27.85 billion; 20%; reliable observed costs: US$26.69 billion; 52%). The proportion of damage-loss and management costs differed substantially across European countries (Figure 3). The distribution of reliable, observed cost types also varied by impacted sectors (Figure 2b). Damage-loss costs constituted the majority of costs for agriculture (94%), forestry (91%), fisheries (83%), environment (67%), health (>99%), and public and social welfare (92%), whilst management costs represented the majority of costs incurred by authorities and stakeholders (81%) (Figure 2b).

From impacted sectors, agriculture was the most impacted by biological invasions (US$36.00 billion, 26%), followed by forestry (US$25.08 billion, 18%), authorities and stakeholders (US$21.44 billion, 15%), public and social welfare (US$9.12 billion, 7%), health (US$5.97 billion; 4%), environment (US$938.74 million; <1%), and fisheries (US$495.5 million; <1%) considering total costs. Considering only reliable, observed costs (Figure 2c), agriculture remained the most impacted sector (US$11.96 billion; 23%), followed by authorities and stakeholders (US$2.17 billion; 4%) and the health sector (US$1.54 billion; 3%). With US$34.81 billion (68%), costs attributed to multiple sectors contributed the largest share. Invasion costs to all other sectors were less than US$1 billion per sector. The relative proportion of impacted sectors was not uniformly distributed across European states (Figure 3).

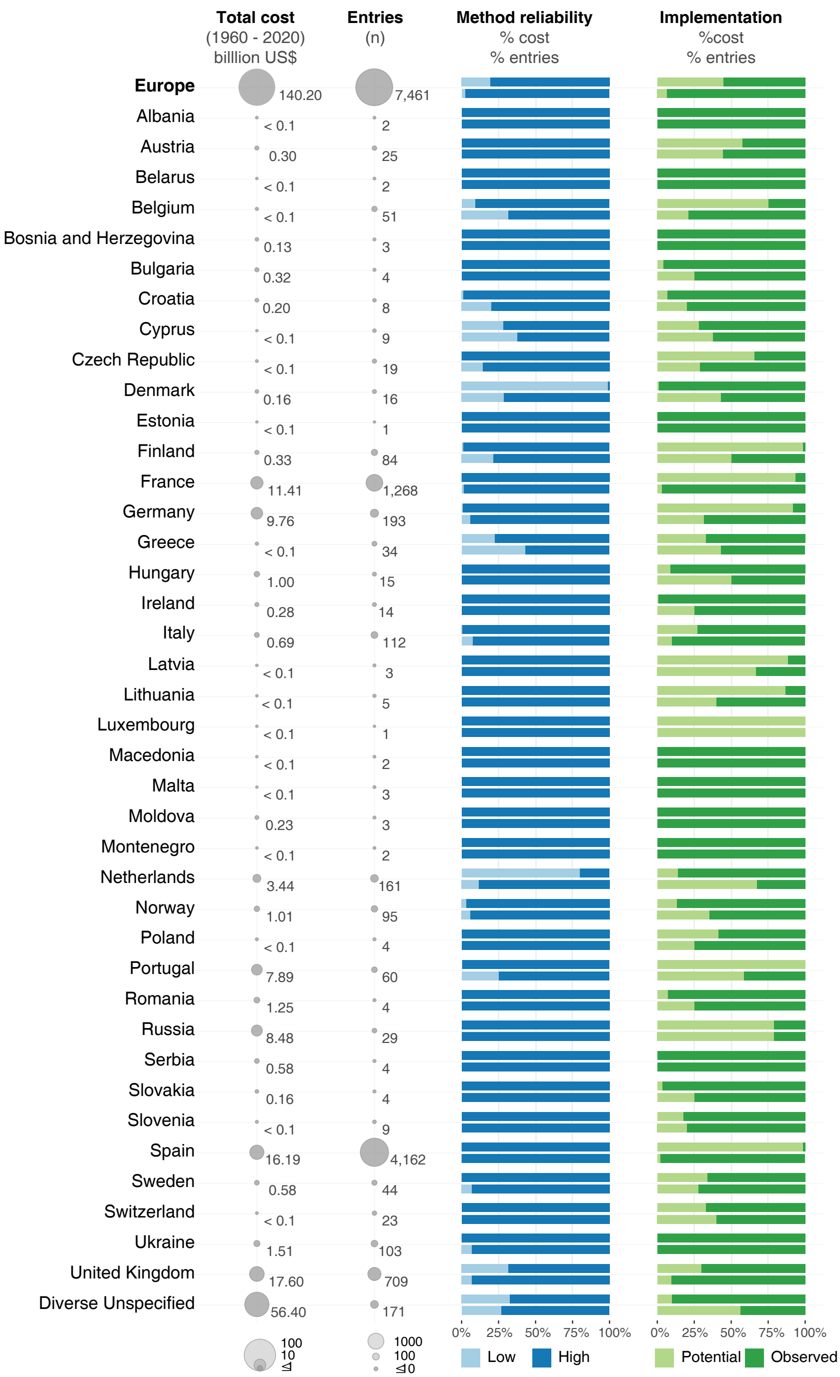


**Figure 1.** Nature of reported costs (monetary totals and numbers of database entries) for IAS across European countries according to percentages considering method reliability (high vs. low) and implementation type (potential vs. observed). Highly reliable figures are from peer-reviewed, official and/or reproducible sources; observed costs have been empirically realised (i.e. excluding expected cost estimations).

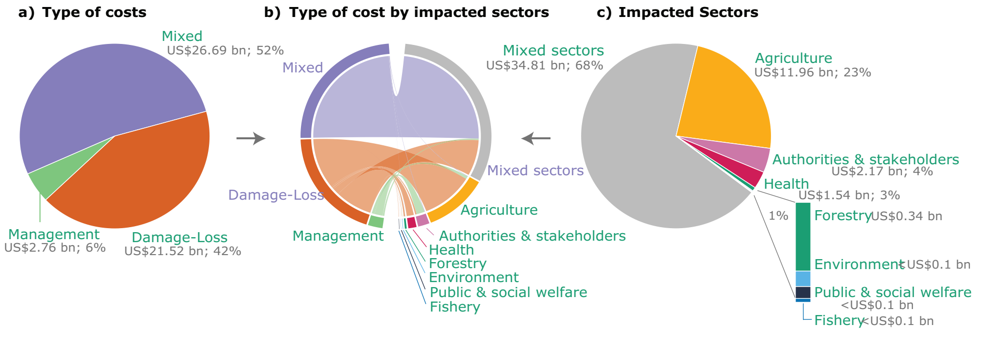


**Figure 2.** Distribution of IAS costs in Europe by **a** type of cost **b** cost type (left half) and impacted sector (right half) and **c** impacted sector. Panel **b** highlights linkages between cost types and impacted sectors, for example 5% (US$2.76/50.97 billion) of total costs were attributed to management, and 64% (US$1.76/2.76 billion) of these costs were incurred in the Authorities and Stakeholders sector, representing 81% (US$1.76/2.17 billion) of costs incurred by the Authorities and Stakeholders sector. Only reliable observed costs are considered (i.e. excluding irreproducible cost estimations and expected costs).

A list of the costliest invasive alien species in Europe can be found in Table 1. Considering all costs, five invertebrates, three vertebrates, and two plants were present in the top 10. When considering only reliable observed costs, three invertebrates, four vertebrates, two plants and one fungi genera were included in the top 10. *Rattus* species had the highest reliable observed costs (4$^{th}$ highest when considering all costs) (reliable: US$6.60 billion; all: US$6.67 billion) spanning across 2 countries. Hereafter, all analyses are performed with Russia omitted.

## Economic cost correlations

Figure 4 highlights the geographical variations in the total cost of invasions throughout Europe, without and with standardization by GDP. There is a positive relationship between the total cost of invasions and country GDP, i.e. countries with a higher GDP tend to have higher reported observed costs (Figure 4c). High costs of invasion compared to GDP were observed in eastern European countries such as Ukraine, Serbia, Romania, Moldova and Hungary, suggesting that this trend may also change when more studies are undertaken or translated (Suppl. material 4).

We found significant positive correlations between damage-loss and management costs with the following socio-economic variables of the considered countries: human population size, land area, GDP, international tourism as expenditures and as number of arrivals. We also found significant positive correlations between management costs and the number of introduced alien species, research effort as the number of papers on the topic of biological invasions and expenditure in R&D, number of researchers, and imports of goods and services, with other tested socio-economic variables showing no significant correlations (Table 2). Moreover, the EU country-specific expenditure in IAS management and in damages-losses induced by IAS were not significantly correlated ($r_s$ = 0.10, $p$ = 0.560).

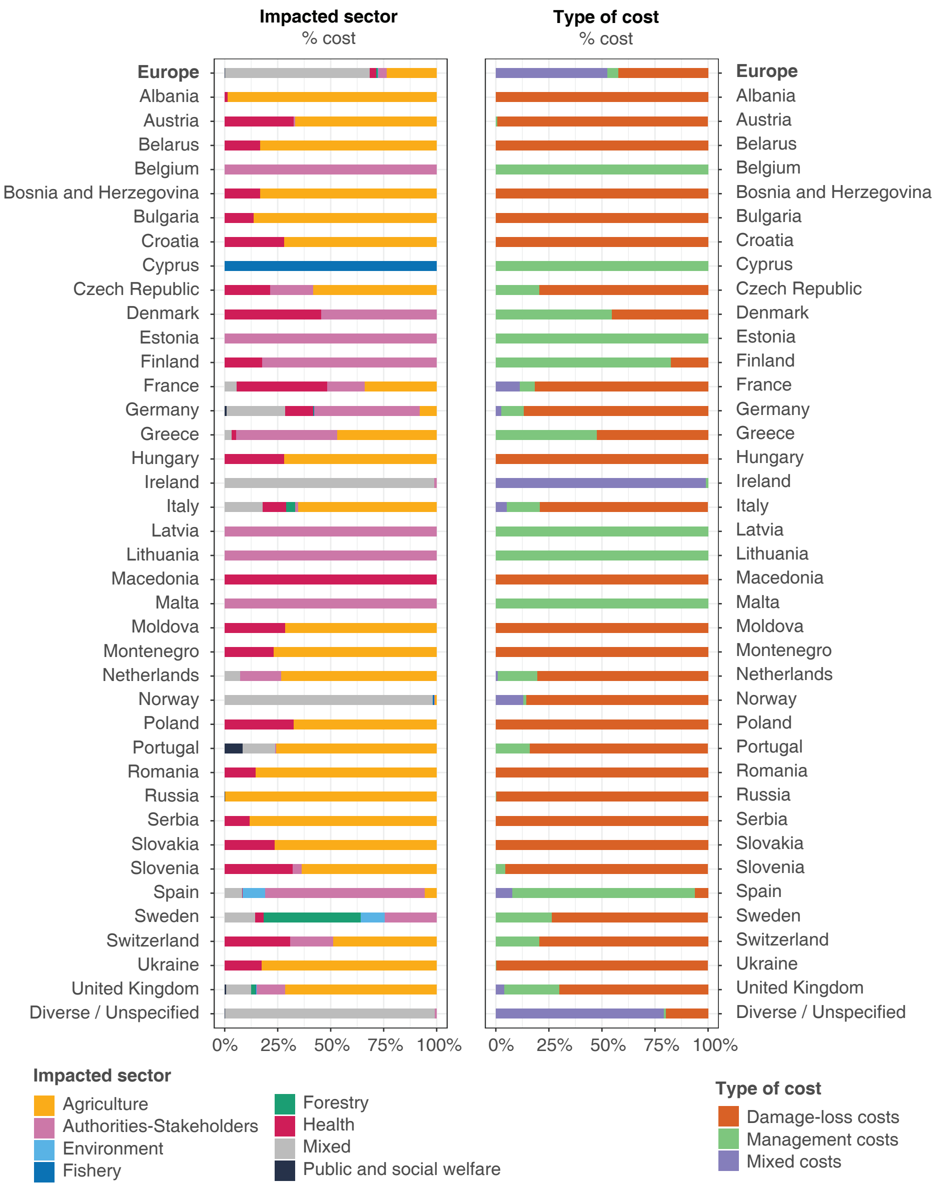


**Figure 3.** Percentage contributions of different impacted sectors and cost types according to country. Only reliable observed costs are considered (i.e. excluding irreproducible cost estimates and expected costs).

## Spatial and taxonomic connectivity of costs

Eight distinct clusters of nodes were found to be strongly interconnected across taxa and countries (Figure 5). These clusters comprised assemblages of typically one or two countries, alongside one or more groups of organisms. The UK was primarily

**Table 1.** Top 10 cost-contributing genera considering (**a**) total and (**b**) reliable observed costs (i.e. excluding irreproducible cost estimations and expected costs), illustrating species taxonomy, total costs and numbers of database entries. Numbers of impacted countries per genus are also shown. Note that costs and entries are pooled across the entire genus (i.e. for all species), with constituent species listed therein.

| (a) Total costs | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Rank** | **Common name** | **Kingdom** | **Phylum** | **Species** | **Total cost (US$ billion, 2017 value)** | **Data entries** | **Number of impacted countries** |
| 1 | Nematode | Animalia | Nematoda | *Bursaphelenchus mucronatus* | 23.38 | 178 | 7 |
| 2 | Ragweed | Plantae | Tracheophyta | *Ambrosia artemisiifolia*<br>*Ambrosia polystachya* | 11.61 | 368 | 29 |
| 3 | Water-primrose | Plantae | Tracheophyta | *Ludwigia grandiflora*<br>*Ludwigia peploides*<br>*Ludwigia repens* | 8.01 | 262 | 5 |
| 4 | Rat | Animalia | Chordata | *Rattus norvegicus*<br>*Rattus rattus* | 6.67 | 45 | 4 |
| 5 | American bullfrog | Animalia | Chordata | *Lithobates catesbeianus* | 6.04 | 38 | 6 |
| 6 | European rabbit | Animalia | Chordata | *Oryctolagus cuniculus* | 4.32 | 57 | 3 |
| 7 | Salmon fluke | Animalia | Platyhelminthes | *Gyrodactylus salaris* | 2.85 | 69 | 2 |
| 8 | Termite | Animalia | Arthropoda | *Cryptotermes brevis* | 2.81 | 4 | 1 |
| 9 | Cucumber beetle | Animalia | Arthropoda | *Diabrotica undecimpunctata*<br>*Diabrotica virgifera* | 2.68 | 59 | 20 |
| 10 | Asian longhorn beetle | Animalia | Arthropoda | *Anoplophora chinensis*<br>*Anoplophora glabripennis* | 1.91 | 35 | 6 |

| (b) Reliable observed costs | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Rank** | **Common name** | **Kingdom** | **Phylum** | **Species** | **Total cost (US$ billion, 2017 value)** | **Data entries** | **Number of impacted countries** |
| 1 | Rat | Animalia | Chordata | *Rattus norvegicus* | 6.60 | 41 | 2 |
| 2 | Ragweed | Plantae | Tracheophyta | *Ambrosia artemisiifolia*<br>*Ambrosia polystachya* | 6.57 | 269 | 29 |
| 3 | European rabbit | Animalia | Chordata | *Oryctolagus cuniculus* | 2.31 | 23 | 2 |
| 4 | Emerald ash borer | Animalia | Arthropoda | *Agrilus planipennis*<br>*Rattus rattus* | 1.81 | 7 | 1 |
| 5 | Salmon fluke | Animalia | Platyhelminthes | *Gyrodactylus salaris* | 0.75 | 32 | 1 |
| 6 | Japanese knotweed | Plantae | Tracheophyta | *Reynoutria japonica* | 0.54 | 91 | 2 |
| 7 | Common pigeon | Animalia | Chordata | *Columba livia* | 0.37 | 1 | 1 |
| 8 | Muskrat | Animalia | Chordata | *Ondatra zibethicus* | 0.35 | 10 | 3 |
| 9 | Dutch elm disease | Fungi | | *Ophiostoma ulmi* | 0.18 | 5 | 2 |
| 10 | Biting midge | Animalia | Arthropoda | *Culicoides imicola* | 0.16 | 1 | 1 |

highly impacted by terrestrial mammals, birds, forbs and aquatic organisms; the Netherlands and Finland by terrestrial arthropods; Norway by aquatic microorganisms; Germany and Estonia by semi-aquatic mammals; Sweden by microorganisms, molluscs and aquatic arthropods/plants; Spain by a diverse array of groups, excepting taxa such as macroalgae and nematodes; and Belgium by semi-aquatic amphibians and terrestrial plants. In turn, the main impacts in France, Italy, as well as in multiple eastern European countries, were caused by terrestrial forbs which turned out to be the costliest group in Europe. Nevertheless, the substantial array of inter-cluster links suggested that European states were each impacted by a diverse array of invasive alien taxa (Figure 5).

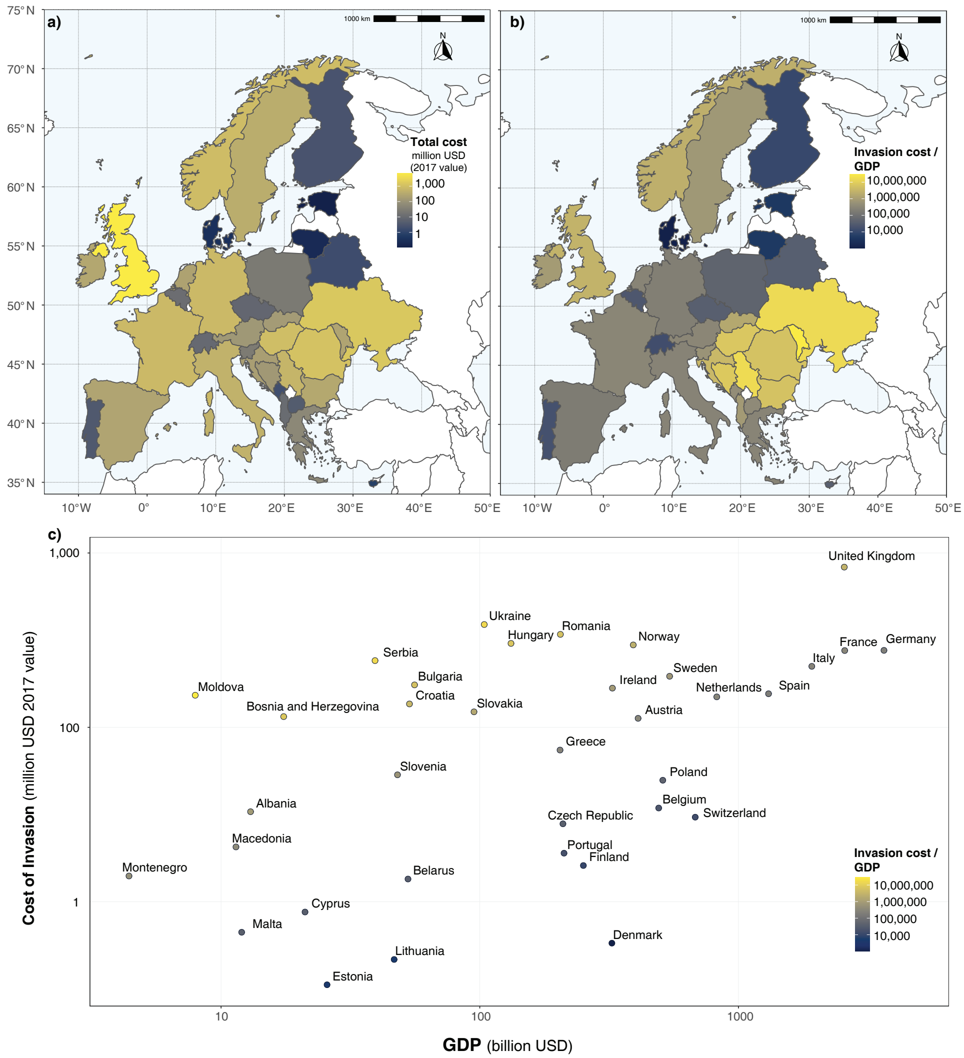


**Figure 4.** Maps showing for each European country where data were available: **a** total reliable observed costs of IAS for the period 1960–2020 in million US$ (i.e. excluding irreproducible cost estimations and expected costs) **b** total reliable observed costs of IAS standardised by GDP (US$), and **c** scatter plot of total cost of IAS against GDP. Data are from **a–c** InvaCost (Ballesteros-Mejia et al. 2020; Diagne et al. 2020a; Angulo et al. 2021b) **b, c** World Bank (2020). Countries in white located in Europe did not have reported costs in the InvaCost database, or in the case of Russia and Turkey were excluded from this analysis due to their transcontinental nature.

## Temporal cost cumulations

Across Europe, biological invasions on average cost 2017 US$2.3 billion (2017 €1.91 billion) annually over the period 1960–2020. While the average annual cost

**Table 2.** Relationships of cost of IAS in European countries with country-specific factors. Two types of costs are included: cost of "Damage-Loss" and cost of "Management". Country-specific factors are presented in Suppl. material 3. Statistics shown are Spearman correlation coefficients (*p*-values associated). Bold numbers indicate significance at the 0.05 level.

| Factor | Damage-Loss | | Management | |
|---|---|---|---|---|
| | $r_s$ | *p* | $r_s$ | *p* |
| Human population size | **0.45** | **0.004** | **0.50** | **0.001** |
| Area | **0.55** | **<0.001** | **0.43** | **0.006** |
| GDP | **0.33** | **0.041** | **0.73** | **<0.001** |
| Number of introduced species | 0.14 | 0.420 | **0.50** | **0.002** |
| Number of invasive alien species | 0.03 | 0.850 | 0.10 | 0.550 |
| Research effort in invasion biology as number of papers on that topic | 0.22 | 0.190 | **0.58** | **<0.001** |
| Research effort as expenditure in R&D in % of GDP | 0.02 | 0.920 | **0.64** | **<0.001** |
| Research effort as expenditure in R&D | 0.29 | 0.086 | **0.75** | **<0.001** |
| Number of researchers | 0.23 | 0.180 | **0.65** | **<0.001** |
| International tourism as expenditures | **0.33** | **0.042** | **0.75** | **<0.001** |
| International tourism as number of arrivals | **0.34** | **0.038** | **0.55** | **<0.001** |
| Imports of goods and services | 0.26 | 0.110 | **0.70** | **<0.001** |

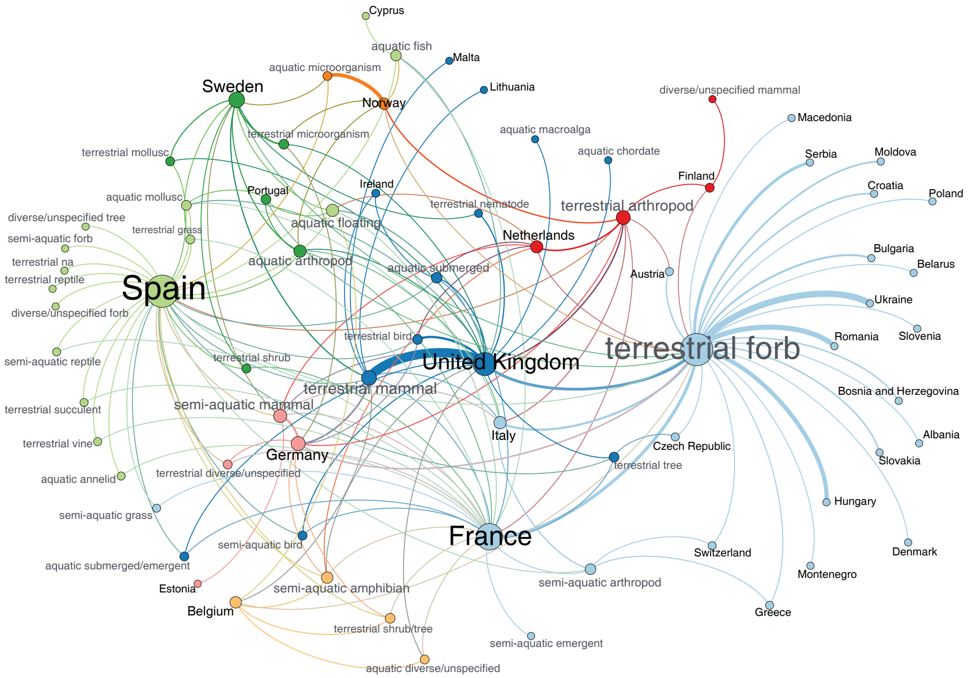


**Figure 5.** European network of IAS costs. This bipartite network is composed of both species and country nodes. Links indicate the cumulative costs of species in European countries over 1960–2020. The larger the link, the higher the cost. Likewise, node size is proportional to the total cumulative cost. For species nodes, node size represents the total cost they had over all countries. For country nodes, the node size represents the total cost of all species in that country. Note that studies reporting costs on 'diverse' groups of organisms rather than specific species were excluded from this network.

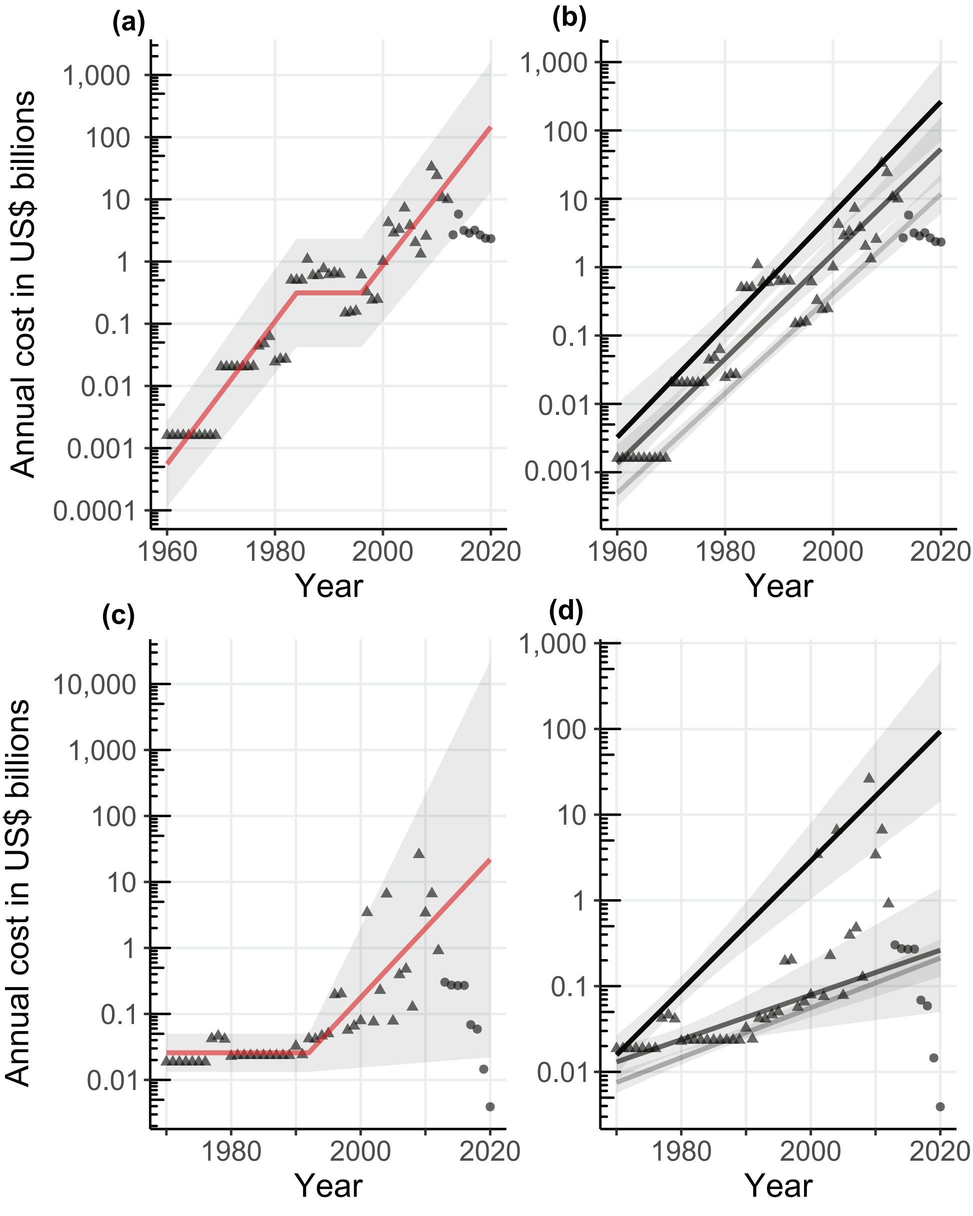


**Figure 6.** Temporal trend of total annual invasion costs recorded in Europe according to multivariate adaptive regression splines (MARS) (**a** red) and quantile regressions; from bottom to top: 0.1: light grey, 0.5: grey, 0.9: dark grey (**b**) between 1960 and 2020, as well as reliable observed costs, MARS (**c** red) and quantile regressions; from bottom to top: 0.1: light grey, 0.5: grey, 0.9: dark grey (**d**) between 1970 and 2020. Error bands on MARS represent prediction intervals (i.e. the interval of cost that any individual year can have). Error bands on quantile regressions represent 95% confidence intervals. Yearly data are triangles (until 2013) and circles (after); only the former are used in the models.

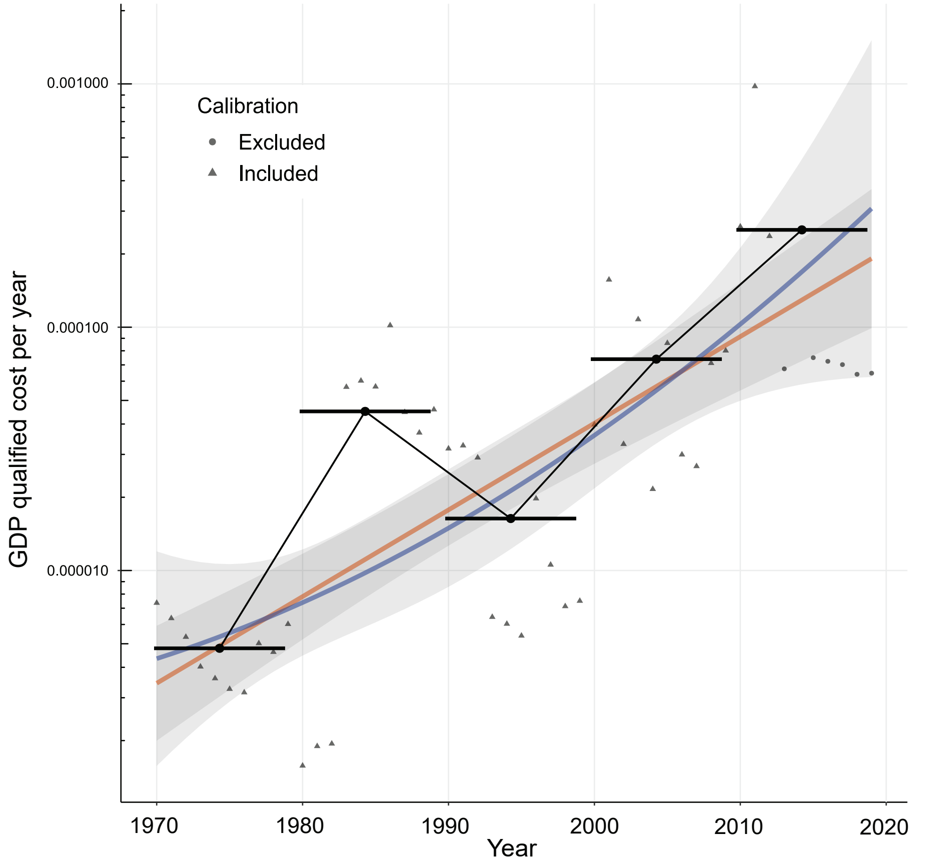


**Figure 7.** Temporal trend of costs considering the GDP-standardized average decadal costs (black bars) and total annual GDP-standardized invasion costs (triangles until 2013, circles after) recorded in Europe (on a log scale). Robust regression analysis between 1970 (the first year of documented reliable observed costs) and 2019 (last year with available GDP data) is overlaid, showing linear regression in orange and quadratic regression in blue. Error bands on robust regressions represent 95% confidence intervals. Model coefficients are presented in Suppl. material 7.

between 1960–1969 was below US\$0.16 billion, it increased to an average annual cost of US\$6.35 billion per year in 2010–2020. Considering only reliable, observed costs, the first database entry occurred a decade later than when considering all costs, totalling at an average annual cost of US\$963.9 million per year (€802.9 million annually). Reliable costs between 1970–1979 averaged US\$26.1 million per year, increasing to US\$3.75 billion per year in 2000–2010 before dropping to US\$944.3 million in 2010–2020, likely due to lags between costs and their reporting.

However, averaging across such long time periods may not clearly demonstrate temporal trends. As such, the best fitting models of temporal cost trends (MARS and quadratic OLS, see Suppl. materials 5, 6) both predict a steep linear increase on a log-scale in IAS driven costs to Europe over the 1960–2013 period (Figure 6). Considering all costs, the best model (MARS: predicted 2013 costs of US$23.58 billion / €19.64 billion; OLS: 0.1$^{st}$ quantile: US$3.62 billion; 0.5$^{th}$ quantile: US$15.57 billion; 0.9$^{th}$ quantile: US$59.02 billion) indicated a 12.6 to 14.1-fold increase every ten years of costs incurred from IAS (Figure 6a, b), while considering only reliable costs (MARS: predicted 2013 costs US$4.07 billion / €3.39 billion; OLS: (0.1$^{st}$ quantile: US$133.18 million; 0.5$^{th}$ quantile: US$172.52 million; 0.9$^{th}$ quantile: US$27.68 billion) suggested a 10.7-fold increase every ten years of reliable observed costs inferred from IAS (Figure 6c, d). If these trends were to continue over the most recent years for which data is incomplete, then extrapolations in 2020 based on MARS models would yield US$139.56 billion / €116.24 for all costs and US$21.98 billion / €18.31 billion for reliable observed costs only.

Considering GDP-qualified economic costs, monetary impacts continued to significantly increase in recent decades (model coefficients shown in Suppl. material 7), irrespective of concurrent economic growth in Europe (Figure 7). Accordingly, the proportional share of GDP devoted to invasion costs has been increasing through time, with invasion costs rising at a greater rate than the rate of economic growth, as evidenced by the steep increase in recent years.

## Discussion

The total cumulative cost of IAS in Europe between 1960 and 2020 was estimated at US$140.20 billion. We identified an exponential increase in the costs of IAS over the studied time period, with costs increasing at least ten-fold every decade. Invasion costs reached US$24 billion in 2013 alone (the last year with 'complete' data), and our model extrapolated 2020 costs of up to US$140 billion. While the reported annual cost of IAS in Europe represented < 0.01% of the European Union (EU) GDP (2017 US$15.3 trillion), it was considerably larger than the annual GDP of national economies such as Malta – in recent years (US$12.8 billion).

While this total may overestimate some individual costs (e.g. in those cases where reported timelines of expenditure for a specific project were unclear in the literature), it remains a highly conservative value given the many challenges attached to assigning costs to IAS impacts. For the purposes of this analysis, we have considered reported costs and expenditure. However, we note that costs of IAS are generally not restricted to directly quantifiable damages or expenditure on management, but also include various indirect costs that are not always easily quantifiable, and therefore not as commonly reported in the literature. For example, many IAS have substantial impacts on human health, native species or ecosystem services that indirectly harm ecosystems and undermine human wellbeing, yet these costs are not easy to capture or quantify (Medlock et al. 2012; Hamaoui-Laguel et al. 2015; Ogden et al. 2019). A striking illustration has been published by Walsh et al. (2016) who reported a significant decrease in the biomass of the grazer *Daphnia pulicaria* in lakes invaded by the spiny water flea *Bythotrephes longimanus*, in turn causing a substantial decrease in water quality by affecting its clarity and total phosphorus content. Other examples include biting nuisances by invasive mosquito species (e.g. *Aedes albopictus*) or invasive ant species (e.g. *Solenopsis invicta*) which can negate recreational activities (e.g. Angulo et al. 2021c); and adverse impacts by invasive tree-boring insects (e.g. *Agrilus planipennis*) on trees that could be costly for the respective economy, although these costs are seldom quantified. Indirect costs are often overlooked or at best underestimated, resulting in minimal investments for alleviation (Rogers et al. 2017; Linders et al. 2019). Although our cost estimations cover 410 species (340 species when considering only reliable observed costs), there remain over ~4,000 IAS in Europe without reported costs (Pagad et al. 2018), indicating that our estimates are highly conservative. Moreover, often costs such as salaries of invasion researchers or managers are not published or accounted for.

Marked differences in cost reporting and totals were found among European countries, with impacts to the UK, Spanish, French, Russian and German economies being most pervasive considering all costs (see Cuthbert et al. 2021a; Angulo et al. 2021a; Renault et al. 2021; Kirichenko et al. 2021; and Haubrock et al. 2021a, respectively). The highest observed costs were found in the UK (Cuthbert et al. 2021a), a country with a long colonial history highly reliant on trade (Clark et al. 2014) and previously identified as a "receiver and donor" country (e.g. for aquatic invasions see García-Berthou et al. 2005). Similar to the UK, the rest of the aforementioned countries with the highest total costs have large economies and most of them were colonial powers, all factors that putatively contribute to high levels of invasions and impacts (Hulme 2009; Hulme et al. 2009). However, the west-European dominance in IAS costs may also be explained by the limited reporting of costs for Eastern European, and potentially also some Nordic, countries. Additionally, the limited reporting of the invasion costs may partly be attributed to the gap of the InvaCost database in sources/documents in languages other than English. The non-English data were collected for only a subset of European languages (Angulo et al. 2021b), leaving aside several languages from Eastern and Northern Europe (e.g. Romanian, Hungarian, Serbian, Polish, and Nordic languages – Finnish, Swedish, Danish etc.). For Eastern European countries, e.g. those of the former communist bloc, one reason for their low reported costs may be that up until 1990, there was little documentation of monetary impacts or, if there was, this information was not made publicly available. Further, differences in societal norms, awareness or regulations may contribute to the lower reported costs for Eastern European countries. However, we note that, considering highly reliable observed costs only, Eastern Russia, Ukraine and Romania exhibited relatively high costs. Regardless of the drivers of this limited reporting, it is a concern, considering that coordinated responses and cooperation are key to efficiently managing invasions and mitigating their impacts (Kark et al. 2015; Latombe et al. 2017; Ogden et al. 2019).

Cultural differences among countries, regional perceptions and national priorities may also influence the level and way of reporting, for example through perceived country-specific sectors of economic importance e.g. forestry and agriculture. In some countries, alien taxa such as trees have been perceived to provide cultural heritage services, particularly in areas with lower levels of development and life satisfaction (Vaz et al. 2018), which might influence cost reporting. Our results also reflect the difficulties of identifying how different sectors may have been impacted – a substantial share of reported costs (29%; US$41.17 billion) were not attributed to a single affected sector. Another important driver of differences in reporting across European countries may lie in differences in perceptions of the severity of IAS impacts. For example, a European-wide survey on attitudes towards biodiversity indicated substantial differences between citizens of different countries in their perceptions towards newly introduced plants and animals. Residents of Spain, Portugal and Slovenia were most likely to view them as a great threat to biodiversity, while those from Finland, the Netherlands and Eastern European countries were less likely to be concerned about the threats of introduced species (European Commission 2013, 2015). For Eastern European countries, initiatives during the Soviet Union times to increase production (i.e. in agriculture, fisheries etc.) and support regional employment may have contributed to the view that new species introductions hold large positive economic potential, which later on may have shaped public views and research agendas towards favoring and/or accepting these species (Kourantidou and Kaiser 2019). Furthermore, in European aquatic systems, alien taxa were reportedly introduced to improve yields from fish farming historically, and particularly in human-altered waterbodies (Arbačiauskas et al. 2010). Although the reasons for the differences in perception of IAS as a threat are not well understood, with perception and values attributed to biodiversity being complex but consistent among social categories, gender and age (Atlan and van Tilbeurgh 2019), higher levels of awareness of their harmful impacts can help support more management actions, research investments and increased efforts to document and report costs. However, these also depend on public support, and this may also vary across specific actions or environments (e.g. Perry and Perry 2008; Crowley et al. 2017). Ultimately, the differences in perceptions of IAS among European states could be a major driver in unevenness of cost reporting among nations, as well as through differences in national-scale policy frameworks. A lack of reporting from many states likely renders our totals as underestimates, but the extent of this underestimation probably differs among countries.

Despite this variability in reported economic costs among European countries (in France, for example, <1% of total reported costs were associated with management as compared with 86% in Germany or 92% in the Netherlands; see e.g. Renault et al. 2021; Haubrock et al. 2021a), the majority of costs (US$84.18 billion; 60%) comprised expenditure on damages and losses, while control-related expenditure represented only 20% of all costs (US$28.17 billion). This dominance of damage costs over management investments is paralleled in other regions, such as Asia (Liu et al. 2021), Africa (Diagne et al. 2021b), North America (Crystal-Ornelas et al. 2021), Central/South America (Heringer et al. 2021), and Australia (Bradshaw et al. 2021); but some individual countries appear to have more management costs (Angulo et al. 2021a for Spain; Ballesteros-Mejia et al. 2021 for Ecuador; Watari et al. 2021 for Japan). Similar to Kourantidou et al. (2021), a number of socio-economic factors significantly correlated with both the reported damages and management costs of IAS, namely: human population size, land area, GDP, and international tourism of the studied countries. These predictors help explain some of the discrepancies in shares of IAS management and damages cost across European countries. First, in countries with higher population, larger land areas, and more international tourism, new species are more likely to be introduced, propagate and invade, while higher human population may also result in increased awareness of specific damage types, e.g. to infrastructure (Mooney and Cleland 2001; Hulme et al. 2009; Hall 2015). This might lead to an increased willingness to pay for managing them. On the other hand, higher GDP might lead to higher resources (e.g. funding and capacity) available to understand and manage IAS. Indeed, the strong relationship found between research effort and numbers of researchers and management cost magnitudes exemplifies this point: greater research investments align with higher reporting of management costs. Our results also indicate that increasing imports of goods and services are associated with greater management spending. It may be assumed that money spent on IAS management would be at least a partial reflection of the total damages incurred. However, there was no significant relationship between reported damage-loss and management costs (Table 2). If management expenditure is largely independent of the number of IAS present and their negative economic impacts, this may reflect a fixed budgetary availability (i.e. the funding available for IAS management is independent of the number of IAS and their impacts in the country). Moreover, the overall three-fold difference in damage-related compared to management costs (eight-fold for observed reliable costs) is alarming, particularly given that preventative measures for invasions (which are classified under management in this study) are shown to be effective at reducing costs than longer-term interventions (Leung et al. 2002; Ahmed et al. 2021), and that countries with a higher proportion of money spent on biosecurity experience generally lower damage costs (Jay et al. 2003; Kritikos et al. 2005).

The InvaCost data also indicate more than a 10-fold increase every ten years in costs associated with IAS since 1960. This finding is likely a result of several trends: foremost the increasing number of IAS in Europe (Seebens et al. 2017), global cost trends (Diagne et al. 2021a; Cuthbert et al. 2021c) and the increasing number of publications within the field of invasion science (Richardson and Pyšek 2008). This is followed by the increase in the GDP of most European countries; and the increasing awareness and number of legislative instruments (at national and EU levels) adopted to tackle IAS (Garcıa de Lomas and Vilà 2015; Turbelin et al. 2017, but see Coughlan et al. 2020). These factors likely contribute to a growth in reported costs and also to an increase in budgets over time. With several thousand alien species established in Europe (Dawson et al. 2017) and legislation in place to tackle IAS throughout the continent, it is somewhat surprising that management and mixed costs (which comprise some management component) represent a small proportion of the total. However, this disconnect between resources made available to mitigate invasion impacts and the large number of IAS worldwide is not a trend unique to Europe (Andreu et al. 2009). Management of IAS can be compromised by a range of factors including insufficient knowledge of species origin and biology, lack of appropriate management strategies, societal ignorance, and lack of resources (Sharp et al. 2011; Courchamp et al. 2017; Kirichenko et al. 2019). Financing provided for biomonitoring and/or eradication plans is frequently of insufficient length, compromising outcomes while simultaneously increasing both management and damage costs (Sutcliffe et al. 2018;

Pergl et al. 2019). Further, the insufficient cooperation among and within countries, for example in implementing risk assessments and management planning for IAS, can result in ineffective management strategies (Sharp et al. 2011; Keller et al. 2011). Even if such planning deficiencies are specifically considered, as in the framework proposed by the Convention on Biological Diversity (CBD 2020), the feasibility of management actions remains impaired by the paucity of resources (Heink et al. 2018).

## Conclusion

The cost estimations presented in this publication synthesize the state of knowledge on economic costs associated with IAS at the European level. Such cost information on biological invasions at regional scales is especially important for planning coordinated responses, cooperative action but also for interaction at multiple levels among European countries within the EU or EEA and with non-European countries through e.g. trade agreements. Further, we identified significantly higher costs in recent years than previous estimates of ~€12 billion (Kettunen et al. 2009), despite the identified knowledge gaps for various IAS. This becomes particularly important in light of the effects of past agreements such as the freedoms guaranteed by Article 21 of the Treaty on the Functioning of the EU, with the freedom of movement being linked to the enhanced displacement of various species within Europe (de Sadeleer 2014). From a management co-operation standpoint, whether within the EU or between trading partners within Europe, the economic burden imposed by IAS becomes particularly relevant, given that increasing costs burden certain countries disproportionately, likely putting monetary strain on economically weaker countries. A comprehensive appraisal of costs would ultimately contribute to well-targeted investments into conservation measures on an EU and continental scale.

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## Supplementary material 1

**Dataset used as basis for the analysis**

Authors: Phillip J. Haubrock, Anna J. Turbelin, Ross N. Cuthbert, Ana Novoa, Nigel G. Taylor, Elena Angulo, Liliana Ballesteros-Mejia, Thomas W. Bodey, César Capinha, Christophe Diagne, Franz Essl, Marina Golivets, Natalia Kirichenko, Melina Kourantidou, Boris Leroy, David Renault, Laura Verbrugge, Franck Courchamp

Data type: Dataset/Excel-sheet



Link: https://doi.org/10.3897/neobiota.67.58196.suppl1

## Supplementary material 2

**Description of the impacted sector categories considered in analyses of European invasion costs**

Authors: Phillip J. Haubrock, Anna J. Turbelin, Ross N. Cuthbert, Ana Novoa, Nigel G. Taylor, Elena Angulo, Liliana Ballesteros-Mejia, Thomas W. Bodey, César Capinha, Christophe Diagne, Franz Essl, Marina Golivets, Natalia Kirichenko, Melina Kourantidou, Boris Leroy, David Renault, Laura Verbrugge, Franck Courchamp

Data type: Description/Word-file



Link: https://doi.org/10.3897/neobiota.67.58196.suppl2

## Supplementary material 3

**Descriptions of socio-economic explanatory variables considered at the country level as potential correlates of invasion costs**

Authors: Phillip J. Haubrock, Anna J. Turbelin, Ross N. Cuthbert, Ana Novoa, Nigel G. Taylor, Elena Angulo, Liliana Ballesteros-Mejia, Thomas W. Bodey, César Capinha, Christophe Diagne, Franz Essl, Marina Golivets, Natalia Kirichenko, Melina Kourantidou, Boris Leroy, David Renault, Laura Verbrugge, Franck Courchamp

Data type: Description/Word-file

Explanation note: Descriptions of socio-economic explanatory variables considered at the country level as potential correlates of invasion costs. Factor names are presented alongside their units, description, source and associated hypotheses.



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## Supplementary material 4

**Map of Europe showing (a) the number of alien species, (b) the number of researchers at a scale of thousands, (c) total cost of invasion normalised by the number of alien species and (d) total cost of invasions normalised by the number of researchers by country**

Authors: Phillip J. Haubrock, Anna J. Turbelin, Ross N. Cuthbert, Ana Novoa, Nigel G. Taylor, Elena Angulo, Liliana Ballesteros-Mejia, Thomas W. Bodey, César Capinha, Christophe Diagne, Franz Essl, Marina Golivets, Natalia Kirichenko, Melina Kourantidou, Boris Leroy, David Renault, Laura Verbrugge, Franck Courchamp

Data type: Figure/Word-file

Explanation note: Map of Europe showing (**a**) the number of alien species, (**b**) the number of researchers at a scale of thousands, (**c**) total cost of invasion normalised by the number of alien species and (**d**) total cost of invasions normalised by the number of researchers by country. Data from (**a**) GRIIS (2020), (**b**) UNESCO statistics (2020), **c**) Angulo et al., (2020), Diagne et al. (2021) and GRIIS (2020) and d) Diagne et al. (2020) and UNESCO statistics (2020).



Link: https://doi.org/10.3897/neobiota.67.58196.suppl4

## Supplementary material 5

**Temporal trends in invasion costs considering all and reliable observed data (i.e. excluding irreproducible cost estimates and expected costs), calculated until 2013**

Authors: Phillip J. Haubrock, Anna J. Turbelin, Ross N. Cuthbert, Ana Novoa, Nigel G. Taylor, Elena Angulo, Liliana Ballesteros-Mejia, Thomas W. Bodey, César Capinha, Christophe Diagne, Franz Essl, Marina Golivets, Natalia Kirichenko, Melina Kourantidou, Boris Leroy, David Renault, Laura Verbrugge, Franck Courchamp

Data type: Figure/Word-file

Explanation note: Temporal trends in invasion costs considering all and reliable observed data (i.e. excluding irreproducible cost estimates and expected costs), calculated until 2013. Fitted models are: ordinary least squares regression (OLS; linear and quadratic), robust regression (linear and quadratic), generalised additive (GAM), multiple additive regression splines (MARS) and quantile-quantile regression (0.1, 0.5 and 0.9). Points represent annual invasion costs totals, whilst grey areas represent 95% confidence intervals (prediction intervals in case of MARS); they are represented by circles until 2013 and triangles after.



Link: https://doi.org/10.3897/neobiota.67.58196.suppl5

## Supplementary material 6

**Root-mean-square errors (RMSE) corresponding to models of temporal trends in invasion costs**

Authors: Phillip J. Haubrock, Anna J. Turbelin, Ross N. Cuthbert, Ana Novoa, Nigel G. Taylor, Elena Angulo, Liliana Ballesteros-Mejia, Thomas W. Bodey, César Capinha, Christophe Diagne, Franz Essl, Marina Golivets, Natalia Kirichenko, Melina Kourantidou, Boris Leroy, David Renault, Laura Verbrugge, Franck Courchamp

Data type: Table/Word-file

Explanation note: Root-mean-square errors (RMSE) corresponding to models of temporal trends in invasion costs (ordinary least squares regression: OLS; robust regression: RR; multiple additive regression splines (MARS); generalised additive model: GAM; quantile: QT) and considering all data (a) and reliable observed data (b) (i.e. excluding irreproducible cost estimates and expected cots). Calibrated data applies adjustments to account for time lags in recent years, in contrast to the unadjusted raw data (i.e. all data).



Link: https://doi.org/10.3897/neobiota.67.58196.suppl6

## Supplementary material 7

**Coefficients from linear robust regression model considering temporal trends in invasion costs, qualified per annual GDP among European countries**

Authors: Phillip J. Haubrock, Anna J. Turbelin, Ross N. Cuthbert, Ana Novoa, Nigel G. Taylor, Elena Angulo, Liliana Ballesteros-Mejia, Thomas W. Bodey, César Capinha, Christophe Diagne, Franz Essl, Marina Golivets, Natalia Kirichenko, Melina Kourantidou, Boris Leroy, David Renault, Laura Verbrugge, Franck Courchamp

Data type: Table/Word-file

Explanation note: Coefficients from linear robust regression model considering temporal trends in invasion costs, qualified per annual GDP among European countries.



Link: https://doi.org/10.3897/neobiota.67.58196.suppl7